State of the Science FACT SHEET

Ocean Acidification

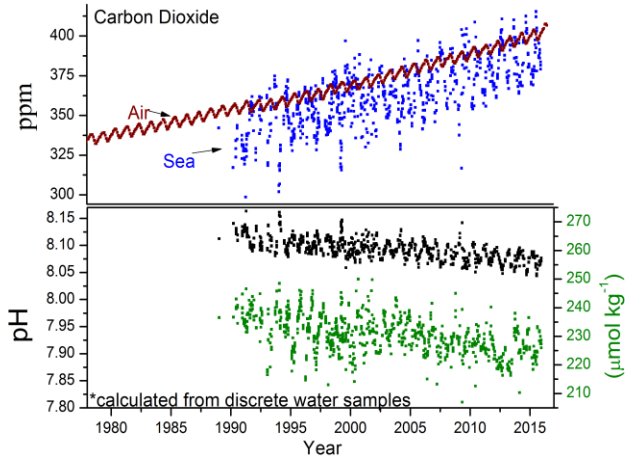
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION • UNITED STATES DEPARTMENT OF COMMERCE

This document represents the state of the science on ocean acidification as developed by NOAA.

What is Ocean Acidification?

Ocean acidification (OA) refers to changes in global ocean carbon chemistry in response to rising levels of atmospheric carbon dioxide When absorbed by ocean and Great Lakes surface waters, CO_2 acidifies them (i.e., reducing pH), increases the carbon content, and causes a decrease in the availability of carbonate ions important to carbonate mineral formation (e.g., shells, reef frameworks, marine sediments). Ocean pH has declined by 0.11 globally since the industrial revolution, an increase in acidity of about 30%. Ocean pH is projected to decline by an additional 0.3 over the next century unless global carbon emissions are significantly curtailed. Such changes are at least ten times faster than at any time over the past 50 million years and can be observed in extended ocean time-series observations. Local factors controlling carbonate chemistry (e.g., upwelling, riverine discharge, nutrient loading, hypoxia, organic carbon remineralization) further modify OA at regional and local scales. Understanding OA and predicting the consequences for marine resources is necessary for informing national and international carbon mitigation discussions and enabling local communities to better prepare and adapt to such changes.

The 'Other' CO_2 Problem



Ocean acidification in the surface ocean near Mauna Loa Observatory in Hawaii. Adapted from Dore et al., 2009. Proc Natl Acad Sci USA 106:12235-12240. As CO_2 increases (top), the ocean's pH and carbonate ion concentrations decline (bottom).

What are the Impacts to Marine Life?

The geological record reveals several acidification events in the distant past which limited the abundance, diversity, and evolution of calcifying organisms throughout the world's oceans. Laboratory and field studies help scientists better understand the implications of modern OA resulting from human activities. These studies demonstrate that many marine species will likely experience adverse effects on health, growth, reproduction, and survival, particularly in early life-stages.

Predicting how OA will impact marine ecosystems and the services they provide demands a multidisciplinary and cross-agency approach.

Species that produce calcium carbonate shells, tests or exoskeletons, like corals, oysters and other molluscs, coralline algae, urchins, and coccolithophores, are generally most sensitive and may calcify slower. Coral reefs will likely experience enhanced bioerosion rates retarding their capacity to recover from acute disturbance events. Recruitment, growth, survival and other calcifer life processes can be effected. Some marine crustaceans (e.g. copepods, crabs, shrimp, krill) may experience decreased survival, growth rate, and egg production. Effects on non-calcifying organisms also have been demonstrated, including on the development of larval stages of some fish and on the functioning of fish nervous and sensory systems (e.g., the ability to detect predators). Some phytoplankton and seagrasses may benefit from OA, likely furthering shifts in community composition as well as potentially increasing the risk of harmful algal blooms.

What Are the Potential Socio-Economic Consequences of Ocean Acidification?

Global marine ecosystem services may be impacted by OA, so socio-economic modeling efforts represent an important aim of the NOAA OA research strategy. Should OA broadly impact marine habitats and alter marine resource availability as anticipated, substantial revenue declines, job losses, and indirect economic costs would occur[1]. Effects to human communities would include changes in shellfish harvest, coral and oyster reef ecosystem services, and indirect impacts across marine food webs. A couple examples are:

- Coral reefs provide habitat for an estimated one million species, and offer food, income, and coastal protection for about 500 million people globally. NOAA has identified OA as a contributing threat to coral reefs in recent Endangered Species Act listings, and EPA provides estimates of coral reef damage[2]. OA serves as an additional stress to an already challenged ecosystem threatened by unsustainable fishing, warming seas, and pollution.

- In 2013, total U.S. shellfish landings were valued at $2.9 billion. OA is already affecting key sectors of this industry. Failures at Pacific oyster hatcheries beginning in 2007 have been linked to OA[3]. This presents a concern for Pacific shellfish aquaculture, which has production valued at over $108 million[4]. Should OA more broadly impact marine ecosystems, the Pacific seafood industry as a whole may see impacts. This industry supports 222 thousand jobs as harvesters, processors, dealers, retailers, and more[5]. In response to OA concerns, Washington State convened a Blue Ribbon Panel that brought together scientists, decision makers, industry stakeholders, tribal representatives, and conservation representatives. The panel produced a set of 42 recommendations to guide Washington's response[6].

[1] Cooley, S. R. and S. C. Doney, 2009. Anticipating ocean acidification's economic consequences for commercial fisheries. *Environmental Research Letters* 4(2): 024007.

[2] EPA. 2015. Climate Change in the United States: Benefits of Global Action. United States Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-15-001.

[3] Ibid.

[4] National Marine Fisheries Service (2014) Fisheries of the United States, 2013. U.S. Department of Commerce, NOAA Current Fishery Statistics No.2013. Available at https://www.st.nmfs.noaa.gov/commercial-fisheries/fus/fus13/index

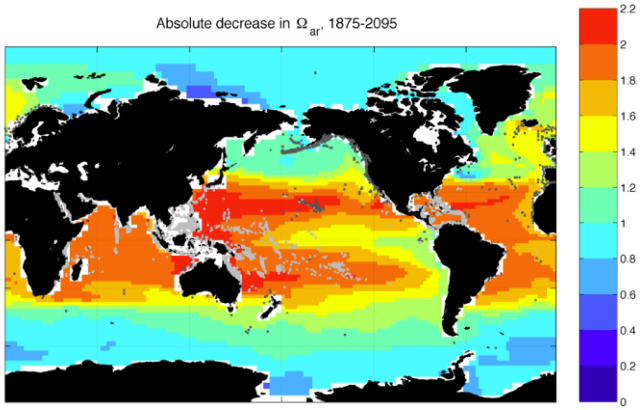
[5] National Marine Fisheries Service (2014) Fisheries Economics of the United States, 2012. U.S. Department of Commerce, NOAA Tech. Memo. NMFS-F/SPO-137. Available at https://www.st.nmfs.noaa.gov/economics/publications/feus/fisheries_economics_2012

[6] Washington State Blue Ribbon Panel on Ocean Acidification (2012): Ocean Acidification: From Knowledge to Action, Washington State's Strategic Response. H. Adelsman and L. Whitely Binder (eds). Washington Department of Ecology, Olympia, Washington. Publication no. 12-01-015. www.ecy.wa.gov

NOAA's Research on Ocean Acidification

NOAA works to improve understanding of OA and impacts to marine resources. The Global OA Observing Network (GOA-ON) is a collaborative initiative to document the status and progression of OA and its impacts on marine ecosystems. The GOA-ON network of surveys and time-series stations that monitor atmospheric and oceanic CO_2 has provided a strong foundation to understand OA globally. Characterizing OA at regional and local scales, particularly within coastal margins and estuaries, remains a key challenge. Knowledge of how local processes can alter the dynamics of OA is needed to inform management actions to prevent, mitigate, or adapt to OA. NOAA is working to establish long-term, high-quality OA observations within ocean, coastal, and coral reef environments. This information is guiding experiments conducted on commercially and ecologically significant organisms to better advance eco-forecasting and socioeconomic modeling efforts. NOAA also continues to develop state-of-the-art Earth System Models of OA projections for use by scientific and resource management communities. Improving our understanding of how OA occurs regionally and teasing out the broad range of vulnerabilities will aid in developing local management and adaptation practices. Finally, informing society about the growing concerns of OA through education and outreach resources is an important part of all NOAA efforts.

A Sea of Change



Shown here is the projected decline in aragonite saturation state (Ω) in response to OA as adapted from Feely et al., 2009[7]. OA is projected to differ between regions whereby tropical waters housing coral reefs will experience the greatest overall change but polar waters will actually become corrosive by 2100.

Additional resources are available from the NOAA Ocean Acidification Program at: www.oceanacidification.noaa.gov.

[7] R.A. Feely, S.C. Doney, and S.R. Cooley. 2009. Ocean Acidification: Present Conditions and Future Changes in a High-CO2 World . *Oceanography* 22(4):36–47, doi:10.5670/oceanog.2009.95.